Effect of Pre-harvest Conditions on Antioxidant Capacity in Fruits

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Abstract

Public interest on the impact of food quality on human health has been increasing. In the past, the agricultural industry was focused on maximizing the quantity of fruits produced for commercial markets. Modern consumers are now interested in optimizing the nutritional composition of foods in order to promote health. Therefore, much attention has now been placed on the agricultural practices which will enhance the nutritional content of horticultural crops being produced today. Fruits have been shown to contain high levels of antioxidant compounds such as carotenoids, vitamins, phenols, flavonoids, dietary glutathione, and endogenous metabolites. These antioxidants can act as free radical scavengers, peroxide decomposers, singlet and triplet oxygen quenchers, enzyme inhibitors, and synergists. The various antioxidant components found in fruits may provide protection against cancer and heart disease, in addition to a number of other health benefits. We found that preharvest conditions such as climate, temperature, light intensity, soil type, compost, mulching, fertilization, increasing carbon dioxide concentration in the atmosphere, and application of naturally occurring compounds, all can affect the antioxidant content and antioxidant activity of the harvested fruits. Many attractive opportunities exist for enhancing the quantity and quality of essential antioxidants present in fruit crops. Discussion will also be made on some strategies for establishing a new research and production paradigm on improving preharvest conditions for enhancing nutritional quality in fruits.

INTRODUCTION

Plants contain many natural antioxidants such as carotenoids, vitamins, phenols, flavonoids, dietary glutathionine, and endogenous metabolites (Larson, 1988). These antioxidants are capable of performing a number of functions including acting as free radical scavengers, peroxide decomposers, singlet and triplet oxygen quenchers, enzyme inhibitors, and synergists (Larson, 1988). The different antioxidant components found in fruits provide protection against harmful free radicals and have been helpful in preventing various human diseases (Ames et al., 1993). Intake of fruits has been associated with decreased rates of cancer and heart disease (Ames et al., 1993; Ascherio et al., 1992). Consumption of fruits can also help in reducing blood pressure, strengthening the immune system, delaying aging, sustaining memory, enhancing the response against pollutants, and reducing inflammation (Ascherio et al., 1992). Therefore, modification of dietary and lifestyle habits can lead to significant improvements in human health.

Fruit crop contain high antioxidant compounds and have high antioxidant capacity. This paper summarizes the antioxidant capacities of various fruit crops and the pre-harvest factors such as crop genotype variation, maturity, climate, temperature, light, soil type, fertilization, culture practices, carbon dioxide concentration in the atmosphere, and the application of naturally occurring compounds on affect the antioxidant content and antioxidant activity of the fruits. The quantity and quality of antioxidants present in fruits could be improved through the selection of different fruit cultivars and improved of pre-harvest conditions.

ANTIOXIDANTS IN FRUITS

Antioxidants can delay or inhibit the oxidation of lipids or other molecules by inhibiting the initiation or propagation of oxidizing chain reactions. The antioxidant activity of phenolic compounds is mainly due to their redox properties which can play an important role in adsorbing and neutralizing free radicals (Larson, 1988). In general, there are two basic categories of antioxidants, natural and synthetic. Recently, interest has been increasing considerably in finding naturally occurring antioxidants for use in foods to replace synthetic antioxidants which are being restricted due to their potential carcinogenicity. The phytochemicals in fruits responsible for antioxidant activity can largely be attributed to phenolic compounds such as anthocyanins and carotenoids, and to other flavonoid compounds.

The anthocyanins are glycosides and acylglycosides of anthocyanidins. Over 250 naturally occurring anthocyanins exist, and are differentiated further by their *O*-glycosylation with different sugar substitutes (Francis, 1989). Glucose, rhamnose, xylose, galactose, arabinose, and fructose are the most common sugars substituted on the aglycon (anthocyanidin). The common anthocyanins are either 3- or 3, 5-glycosylated. Free radical scavenging properties of the phenolic hydroxy groups attached to ring structures are responsible for the strong antioxidant properties of the anthocyanins (Rice-Evans and Miller, 1996). They help reduce damage caused by free-radical activity and low-density lipoprotein oxidation, platelet aggregation, and endothelium-dependent vasodilation of arteries (Heinonen et al., 1998). The other flavonoids, flavones, flavonols, and their glycosides occur in nearly all our common fruits. These flavonoids have demonstrated antioxidant and antitumor properties and also have applications as antibiotic, anti-diarrheal, antiulcer and anti-inflammatory agents as well as in the treatment of diseases such as hypertension, vascular fragility, allergies, and hypercholesterolemia (Rice-Evans and Miller, 1996; Heinonen et al., 1998).

Carotenoids are found in many fruits such as mango, papaya and orange fruits. They are comprised of a set of several hundred pigmented, fat soluble antioxidants. The most abundant carotenoids are α-carotene, β-carotene, lycopene, lutein, zeazanthin, and β-cryptozanthin. The nature of the carotenoids affects its bioavailability. For example, lutein is five times more readily available in the human body than β-carotene. The combination of fatty foods with carotenoid-rich fruits enhances carotenoids uptake (Gartner et al., 1997). Epidemiological studies have shown that the increased consumption of foods rich in carotenoids is correlated with a diminished risk for several diseases (Giovannucci, 1999). β-carotene is the essential precursor to retinol or vitamin A (Giovannucci,1999). Recent studies have suggested that β-carotene itself may reduce the risk of cancer and heart disease even before being converted into vitamin A and may account for much of the health benefits attributed to fruits. As an excellent antioxidant and radical trapping agent, β-carotene has the capability to protect membranes, DNA, and other cellular constituents from oxidative damage (Byers and Perry, 1992).

Vitamin C occurs naturally in citrus fruits, strawberries, and other fruits. It is highly water-soluble. Vitamin C has powerful antioxidant properties and indirectly contributes to several key oxidative and reductive enzyme systems, and has ability to regenerate other biologically important antioxidants, such as glutathione and vitamin E, into their reduced state (Jacob, 1995). It has been reported that the reducing power of vitamin C is capable of neutralizing most of the physiologically relevant reactive oxygen and nitrogen species in the human body (Buettner, 1993).

ANTIOXIDANT CAPACITY OF FRUITS

In general, the components in fruits can be divided into two fractions, lipophilic and hydrophilic. The range of hydrophilic antioxidant capacities (H-ORAC$_{FL}$) was large among the different fruits, such as prunes, raisins, blackberries, black currants, blueberries, raspberries, strawberries, grapes, pomegranates and some varieties of apples (Prior et al., 1998; Wu et al., 2004). H-ORAC$_{FL}$ for all of the melons was relatively low. Genetic factors play an important role in determining antioxidant capacity in crops. For many crops, a large variety of genotypes exist and thus there is potential for genetic variability relating to antioxidant activity. The effect of genotype variation on antioxidant activities has also received much attention in grapes (Lee and Talcott, 2004), plums (Gil et al., 2002), apples (Wolfe et al., 2003), citrus (Bocco et al., 1998), guavas (Jiménez-Escrig et al., 2001), and nectarines and peaches (Gil et al., 2002). Among the small fruits, blueberries, black raspberries and blackberries have higher antioxidant activities, while strawberries generally have lower values of total antioxidants (Wang and Lin, 2000). Häkkinen et al. (1999) also found that extracts of crowberry, cloudberry, whortleberry, cowberry, aronia, rowanberry and cranberry had high antioxidant activities, while red currant, black currant, and strawberry had relatively low activities. These results correlate with the findings that black raspberries and blackberries contain high amounts of cyanidin glycosides, a strong antioxidant, while strawberries contain pelargonidin 3-glucoside and ascorbic acid, which are weak antioxidants (Gil et al., 1997). Among the anthocyanins, the relative antioxidant strength in preventing oxidation of human low-density lipoprotein is as follows: delphinidin > cyanidin > malvidin > pelargonidin (Satué-Gracia et al., 1997). There is also a large range for lipophilic antioxidant capacities (L-$ORAC_{FL}$) for different fruits. Compared to H-$ORAC_{FL}$ in fruits, L-$ORAC_{FL}$ values were generally low (Wu et al., 2004). L-$ORAC_{FL}$ values for fresh fruits could be as low as 0.07 μmol of Trolox (TE)/g fresh weight for tangerines and as high as 5.52 μmol of TE/g fresh weight in avocados. (Wu et al., 2004). Among all berry fruits, cranberries, raspberries and blackberries have the highest L-$ORAC_{FL}$ values with > 1 μmol of TE/g fresh weight (Wu et al., 2004).

The peroxyl radical is the most common free radical in human biology, but radicals of superoxide radicals, hydrogen peroxide, hydroxyl radicals, and singlet oxygen are all present in biological systems. Different species or different cultivars showed varying degrees of scavenging capacity on different active oxygen species. The scavenging capacity for blackberries, blueberries, cranberries, raspberries, and strawberries ranged from 40.8 to 72.0% for superoxide radicals, from 50.7 to 73.9% for hydrogen peroxide, from 52.4 to 77.3% for hydroxyl radicals, and from 6.3 to 17.4% for singlet oxygen. Antioxidant capacity also varies considerably with different stages of maturity. Many phytonutrients are synthesized in parallel with the overall development and maturation of fruits. Therefore, antioxidant capacity varied considerably with different levels of maturity. Blackberry, raspberry and strawberry fruits harvested during their ripe stage consistently yielded higher antioxidant values than harvest in the pink stage (Wang and Lin, 2000). Younger blueberries harvested at an early stage had lower antioxidant and total anthocyanins compared to more mature blueberries which were not harvested until 49 days later (Prior et al., 1998).

EFFECT OF PRE-HARVEST CONDITIONS ON ANTIOXIDANT CAPACITY IN FRUITS

Environment Conditions and Geographical Variation

Preharvest conditions of fruits such as growing temperature and light intensity can affect phytonutrient content. Strawberries grown with higher light intensity results increased levels of ascorbic acid. Growth strawberry under different growing temperatures (day/night) could also affect antioxidant activity and total flavonoid content. High temperature growing conditions (25/30ºC) significantly enhanced antioxidant activity, as well as anthocyanin and total phenolic content. Meanwhile, plants grown in the cool day and night temperature (18/12ºC) treatment produced fruit which generally had the lowest antioxidant activity (Wang and Zheng, 2001).

The effect of geographical variation, month-to-month and year-to-year difference on the antioxidant capacity of various fruits is well described and is likely also due to environmental conditions. Vitamin C content was found difference in processed Florida orange and grapefruit juices (Lee and Coates, 1997). One explanation for this difference could be related to different flavonoid concentrations (Wang and Zheng, 2001). The composition of flavonols in red raspberry juice was also influenced by cultivar, and environmental factors (Rommel and Wrolstad, 1993). Abiotic conditions (temperature, moisture, irradiation, soil fertility) can vary markedly from year to year and affect the content of phenolic components. Kalt and McDonald (1996) found that seasonal variation in anthocyanin content among lowbush blueberry cultivars over seven seasons was quite marked in fruit harvested from the same site. Connor et al. (2002) found that antioxidant content varied significantly in blueberry fruit harvested in Minnesota, Michigan and Oregon among the cultivars across location and years. This may reflect differences in climate and cultural practices among locations, including differences in ultraviolet radiation, temperature, or water stress, or mineral nutrient availability (Connor et al., 2002). Goncalves et al. (2004) found that the level of phenolic acids were higher in 2001 and anthocyanin levels were higher in 2002 in cherry fruit. Ascorbic acid content in strawberries is also highly affected by climate conditions and growing area. Olsson et al. (2004) showed some variation in antioxidant activity, ascorbic acid content and ellagic acid content between 1999 and 2000 within each strawberry cultivar. These data suggest a significant influence of climatic conditions on antioxidant activity.

Cultural Practices

Soil types, composts, mulching and fertilization influence the water and nutrient supply to the plant and can affect the nutritional composition and antioxidant activity of the harvested fruit. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat lower ascorbic acid content in citrus fruits, while increasing potassium fertilization increases their ascorbic acid content (Nagy, 1980). Strawberry plants grown with different soil nutrients also show differences in ascorbic acid content. Plants grown in low-organic-matter and low-cation-exchange-capacity sandy soil amended with calcium, magnesium, and nitrogen produced more ascorbic acid in their fruit than plants without supplemental fertilizer (Penalosa et al., 1994). In green-flesh honeydew muskmelons, the total ascorbic acid and folic acid are higher when grown on clay loam versus sandy loam soil (Lester and Crosby, 2002). Sandy loam soil produces less β-carotene as compared with sandy loam soils in orange-fleshed muskmelon fruit (Lester and Eischen, 1996).

Composts have been utilized in agriculture as a significant source of organic matter. As a soil supplement, compost significantly enhanced content of ascorbic acid and flavonoids in strawberries. The free radical absorbance capacities for peroxyl radical, superoxide radical, hydrogen peroxide, hydroxyl radical and singlet oxygen in strawberries increased significantly with increasing compost use. Strawberry plants grown with compost yielded fruits with high levels of phenolics, flavonol, and anthocyanin content (Wang and Lin, 2003). It is possible that compost causes changes in soil chemical and physical characteristics, increases beneficial microorganisms, and increases nutrient availability and uptake, thus favoring plant and fruit growth.

Food products from organic farming are believed to be healthier than the corresponding conventional foods. Carbonaro et al. (2002) found a parallel increase in polyphenol content and polyphenoloxidase activity of organic peaches and pears compared with the corresponding conventional samples. Ascorbic acid was higher in organic than conventional peaches and α-tocopherol also increased in organic pears. Lombardi-Boccia et al (2004) found that ascorbic acid, α-, γ-tocopherols, and β-carotene were higher in organic plums grown on soil covered with natural meadow and total polyphenols and quercetin were higher in conventional plums, but myrecitin and kaempferol were higher in organic plums. Asami et al. (2003) showed that higher levels of total phenolics were consistently found in organically and sustainably grown cultivations of marionberry and strawberry as compared to those produced by conventional agricultural practices. These data provide evidence that an improvement in the antioxidant defense system of the plant occurred as a consequence of the organic cultivation practice.

Different cultural systems had varying effects on antioxidant activity, anthocyanin, and total phenolic content in various strawberry cultivars. The hill black plasticulture (HC) system consistently resulted in significantly higher levels of flavonoids, anthocyanin, total phenolic content and antioxidant activity, compared to the matted row (MR) cultural system. In general, phenolic acid and flavonol content, as well as cyanidin-and pelargonidin-based anthocyanins and total flavonoids are greatest in the HC system. Fruit grown under HC conditions also have the highest peroxyl radical absorbance capacity (Wang et al., 2002). Different cultural systems probably led to differences in canopy temperature, soil temperature and moisture content, and the quantity and quality of light transmitted, reflected or absorbed. These differences in turn may have affected plant growth, development, and fruit quality and carbohydrate metabolism in strawberry plants (Wang et al., 2002).

Jasmonic acid (JA) and its methyl ester (methyl jasmonate, MJ) are a class of oxylipins derived from lipoxygenase-dependent oxidation of fatty acid. Both compounds have been found to occur naturally in a wide range of higher plants. MJ treatments significantly enhanced anthocyanin, total phenolic, and flavonoid content and antioxidant capacity.content in raspberries. Stimulation of anthocyanin content by MJ has been reported during in vitro strawberry ripening (Pérez et al., 1997). MJ also significantly enhanced flavonoid content and antioxidant capacities in the fruit.

CONCLUSIONS

Fruits contain many benefits for human nutrition and health promotion. Technological advances in genomics, plant breeding, bioengineering, and biotechnology now make it possible to create foods which will have maximal nutritional content, by manipulating field growing conditions and food processing. Therefore, there is great potential for enhancing the antioxidant capacity of fruits through plant breeding and selection. Pre- harvest factors may affect the content and stability of phytochemicals with nutritional value. In addition, fruit crops maturity also significantly influences the antioxidant capacity. Modern technology could indirectly increase the nutritional value of fruits would be to delay the softening process so that fruits could be harvested at a later, more mature stage, when more of the phyto-compounds have been bio-synthesized. Post-harvest factors such as transport and storage can also influence phytochemical composition of food crops. New research is ongoing to assess the impact of different handling techniques on the nutritional content of fruits. Knowledge gained from these research efforts will be helpful in improving health by maximizing the nutrient content and quality of diet for human consumption.

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